

**NASA**

for

**SPACE**

utilization

**ENGINEERING**

of local

**RESEARCH**

planetary

**CENTER**

resources

1330

**LUNAR  
MATERIALS TECHNOLOGY  
SYMPOSIUM**

**Proceedings**

(NASA-CR-192881) PROCEEDINGS OF  
THE LUNAR MATERIALS TECHNOLOGY  
SYMPOSIUM (Arizona Univ.) 363 p

N93-27956  
--THRU--  
N93-27988  
Unclass

G3/91 0158314

# CONTENTS

	Page
Introduction	i - <i>PRIMORDIAL</i>
<b>Resource Characterization</b>	
The Challenges and Benefits of Lunar Exploration <i>Aaron Cohen</i>	I-1
Return to the Moon: Lunar Robotic Science Missions <i>Lawrence A. Taylor</i>	I-7 - 2
Characterization of Lunar Surface Materials For Use in Construction <i>Stewart W. Johnson and Jack O. Burns</i>	I-17 - 3
An Engineer/Constructor's View of Lunar Resource Development <i>Carleton H. Jones</i>	I-23 - 4
<b>Energy Management</b>	
Energy for Lunar Resource Exploitation <i>Peter E. Glaser</i>	II-1 - 5
Advanced Photovoltaic Power Systems Using Tandem GaAs/GaSb Concentrator Modules <i>L.M. Fraas, M.S. Kuryla, D.A. Pietila, V.S. Sundaram, P.E. Gruenbaum, J.E. Avery, V. Dinh, R. Ballantyne, and C. Samuel</i>	II-9 - 6
An Evolution Strategy for Lunar Nuclear Surface Power <i>Lee S. Mason</i>	II-22 - 7
Earth to Space Power Beaming: A New NASA Technology Initiative <i>John D.G. Rather</i>	II-36 - 8
Fuel Cell Technology for Lunar Surface Operations <i>Henry J. DeRonck</i>	II-37 - 9
Electrical Power Integration for Lunar Operations <i>Gordon Woodcock</i>	II-41 - 10
<b>Materials Processing</b>	
Oxygen Production on the Lunar Materials Processing Frontier <i>Barbara H. Altenberg</i>	III-1 - 11
Magnetic Beneficiation of Lunar Soils <i>R.R. Oder, J. Graf, L.A. Taylor, and D.S. McKay</i>	III-15 - 12
Propellant Production and Useful Materials: Hardware Data From Components and the System <i>Kumar Ramohalli</i>	III-24 - 13
Metals Production <i>Theodore R. Beck</i>	III-41 - 14

## Materials Processing (cont.)

Glasses, Ceramics, and Composites From Lunar Materials <i>George H. Beall</i>	III-54 -15
Lunar Materials Processing System Integration <i>Brent Sherwood</i>	III-67 -16
The On-site Manufacture of Propellant Oxygen from Lunar Resources <i>Sanders D. Rosenberg</i>	III-80 -17

## Environment Control

Options for a Lunar Base Surface Architecture <i>Barney B. Roberts</i>	IV-1 -18
Engineering Design Constraints of the Lunar Surface Environment <i>D.A. Morrison</i>	IV-16 -19
Closed Ecological Systems: From Test Tubes to Earth's Biosphere <i>Robert J. Frye and George Mignon</i>	IV-18 -20
SPE Water Electrolyzers in Support of the Lunar Outpost <i>J.F. McElroy</i>	IV-37 -21
Assessment of the State of the Art in Life Support Environmental Control For SEI <i>Charles H. Simonds and Gary P. Noyes</i>	IV-57 -22
Dust Protection for Environmental Control and Life Support Systems in the Lunar Environment <i>Susan Fuhs and Jeffrey Harris</i>	IV-71 -23

## Automation and Communications

Intelligent Robots for Planetary Exploration and Construction <i>James S. Albus</i>	V-1 -24
Flexible Control Techniques for a Lunar Base <i>Thomas W. Kraus</i>	V-16 -25
The Use of Automation and Robotic Systems to Establish and Maintain Lunar Base Operations <i>Lyman J. Petrosky</i>	V-24 -26
Considerations for Lunar Colony Communications Systems <i>Richard P. Dowling</i>	V-30 -27

## Poster Presentations

Regolith Thermal Energy Storage for Lunar Nighttime Power <i>Brian Tillotson</i>	VI-1 -28
Lunar Base Thermal Management/Power System Analysis and Design <i>Jerry R. McGhee</i>	VI-9 -29
Rectenna Thermal Model Development <i>Murali Kadiramangalam</i>	VI-21 -30
Choice of Antenna Geometry for Microwave Power Transmission From Solar Power Satellites <i>Seth D. Potter</i>	VI-34 -31

PRIMARY

## INTRODUCTION

The Third Annual Symposium of the University of Arizona/NASA Space Engineering Research Center (SERC) was held February 20-22, 1992, in Tucson. Because of common interests in promoting In-Situ Resource Utilization (ISRU) and Indigenous Space Materials Utilization (ISMU), the Symposium was sponsored jointly by the UA/NASA SERC and the Indigenous Space Materials Utilization Advisory Panel, founded by the Lunar and Planetary Institute in October 1990.

The meeting was organized around a possible Lunar Outpost scenario, featuring industrial technologies, systems, and components applicable to the extraction, processing, and fabrication of local materials. Structuring the Symposium in this novel way grew out of discussions between the UA/NASA SERC and the ISMU Advisory Panel. Detailed planning by a subcommittee that included members from both groups resulted in a specific description of an initial Lunar Outpost (reproduced below) in all its aspects, including crew, structural, power, transportation, and supply requirements. Industrial technologies applicable to the processing of local resources were to be stressed.

From this organizational structure grew a most unusual list of participants. In addition to acknowledged space resources experts, the Symposium brought together investigators from outside the field whose knowledge could be applied to space development activities. Presentations came from a variety of specialists in fields such as minerals processing, environmental control, and communications.

The three days were divided into sessions devoted to five major topics; their titles are indicative of the diversity this Symposium offered. The first day opened with a session on *Resource Characterization* that included presentations delivered by experts from NASA Headquarters, Southern Methodist University, the Lunar and Planetary Institute, Bechtel Inc., BDM International, and the Institute for Space Science and Technology. Dr. S. Fred Singer, Distinguished Research Professor with the Institute for Space Science and Technology, delivered a luncheon address on "Project SPACE (Solar Power and Climate Equalizer): SPS Used for Global Climate Modification." The second session of the opening day focused on *Energy Management*; featured were presentations by representatives from Arthur D. Little, Boeing, International Fuel Cells Corp., NASA Headquarters, and NASA Lewis.

The morning session of day two was entitled *Materials Processing*, which brought together specialists from Rockwell International, Bechtel National, EXPORTech Inc., Corning, Electrochemical Tech, Boeing, and UA/NASA SERC. Dr. William L. Smith of NASA Headquarters delivered the luncheon address, "Precursor Missions to Mars." The afternoon session, *Environment Control*, included presentations by experts from Lockheed, NASA Johnson, the Environmental Research Laboratory, Hamilton Standard, and Allied Signal Aerospace. Dr. Louis Friedman, the Executive Director of the Planetary Society, spoke on "International Prospects for Planetary Exploration" at the evening banquet.

Day three opened with a session entitled *Automation and Communications*. Papers were delivered by experts from the National Institute of Standards and Technology, Intec Controls, Westinghouse Electric, Creativision Consulting, and GCI. A *Recommendations* session followed. The distinguished Enabling Technologies Panel consisted of Hubert P. Davis of Davis Aerospace; Benton Clark of Martin Marietta; Murray Hirschbein from NASA Headquarters; Daniel J. Lancaster of Fluor Daniel; John S. Lewis, UA/NASA SERC Co-director for Science; and Gordon Woodcock of Boeing. The luncheon address, "Lunar Materials for the Space Economy" by Dr. James R. Arnold of the

University of California, San Diego, concluded the Symposium. Throughout the three days, *Poster Presentations* from Boeing, Aerojet Propulsion Division, New York University, UA/NASA SERC were available to Symposium participants.

The Third Annual Symposium was clearly successful in achieving its aim. The somewhat unconventional list of experts who spoke provided a refreshing diversity of approaches to some old problems, as well as a variety of new ideas. The format of the Symposium served to introduce specialists representing a wide spectrum of industrial expertise to space resources experts in government and academia. This meeting and others like it may well provide the groundwork for future collaborations to develop extraterrestrial resources. As the recognized meeting place for experts working in the field of space resources development, the UA/NASA SERC will continue to provide opportunities such as this to insure a stimulating and creative exchange of ideas among government, the private sector, and academia.

The following pages contain the papers delivered at the Symposium. Some authors were unable to provide copies of their addresses; in those cases their abstracts have been included in these Proceedings.

-- T. Triffet  
Director, UA/NASA SERC

### **Lunar Outpost Scenario**

To focus the presentations it is assumed that: (1) this will be an evolving facility with growing capabilities and needs tended by 5, increasing to 10, astronauts and mission specialists. (2) The initial base will consist of a landing area, a shelter, a solar or nuclear power area, and science and engineering experimental areas. (3) This will require 50 to 100 kw of electrical power; but when permanent occupation begins, probably within two years, a larger habitat and several hundred kilowatts to a megawatt of power will be needed. (4) A utility vehicle that can be used for transporting crew and supplies, as well as for digging, scraping, and lifting, will be available.

(5) The crew will conduct a variety of science and materials utilization experiments. The first of the latter type will include demonstrations of the production of oxygen from soils and rocks, of the extraction and collection of solar wind-implanted gases such as hydrogen, carbon dioxide, and nitrogen, of the fabrication of ceramic bricks, and of the production of various metals and composite materials.

(6) These early basic experiments will be replaced by small pilot plants capable of producing useful amounts of oxygen, volatiles, ceramics, metals, and composites, as well as a few simple products such as bricks of several types, beams, columns, pipes, and membranes.

(7) Oxygen production rates will grow from pilot plant rates of 5-10 tonnes/year to mature plant rates of 25-50 tonnes/year -- enough to fuel a lander to and from lunar orbit. Production of construction materials will grow to rates of hundreds of tonnes/year -- materials that will be used for the construction of shelters, for radiation shielding, for paving landing pads and roads, and erecting blast shields. Eventually local materials will be used to build complete habitats, new power systems, and other essential infrastructure.

**Back to the Future**

A.I. in Space: Past, Present, and Possible Futures  
*Donald D. Rose and Jonathan V. Post*

VII-1 -32

**Panel Discussion**

Summary of Discussions: Enabling Technologies Panel  
*Hubert P. Davis*

VIII-1

Contribution to the Panel Discussion  
*John S. Lewis*

VIII-5

